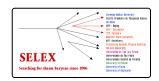# Recent Results on Doubly Charmed Baryons

CIPANP May 20, 2003
Peter S. Cooper
Fermi National Accelerator Laboratory

Outline

➤ Brief theory and model review

➤ Search methods and Previous results

➤ Where are the isospin partners?

➤ New States - A pair of Isodoublets?

➤ What are these? Properties and production

➤ Conclusions

SELEX Collaboration

First Observation of the Doubly Charmed Baryon Ξ_{cc}^+

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We observe a signal for the doubly charmed baryon Ξ_{cc}^+ in the charged decay mode $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ in data from SELEX, the charm hadroproduction experiment at Fermilab. We observe an excess of 15.9 events over an expected background of 6.1 ± 0.5 events, a statistical significance of 6.3σ. The observed mass of this state is 3519 ± 1 MeV/c^2. The Gaussian mass width of this state is 3 MeV/c^2, consistent with resolution; its lifetime is less than 33 fs at 90% confidence.
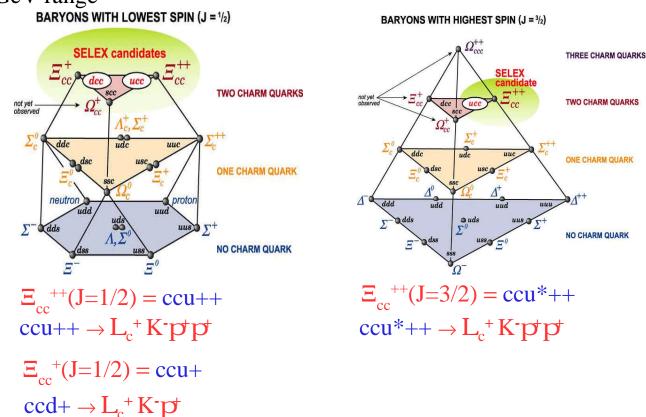
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Published by The American Physical Society
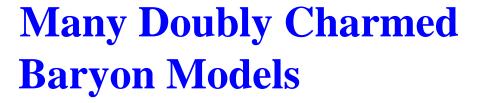
Some Nomenclature
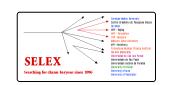
In this talk we replace PDG names with suggestive labels. While SU_4 is badly broken by the charm mass it still classifies all the states .There are many model predictions in the 3.5-3.8 GeV range

BARYONS WITH LOWEST SPIN (J = 1/2)

SELEX candidates

Ξ_{cc}^+ dcc   ucc Ξ_{cc}^{++}

scc

TWO CHARM QUARKS

not yet observed → Ω_{cc}^+

Λ_c^+, Σ_c^+

Σ_c^0 ddc   udc   uuc Σ_c^{++}

dsc   usc

Ξ_c^0 ssc Ξ_c^+

Ω_c^0

neutron   proton

ONE CHARM QUARK

udd   uud

Σ^- dds   uds   uus Σ^+

Λ, Σ^0

dss   uss

Ξ^- Ξ^0

NO CHARM QUARK

BARYONS WITH HIGHEST SPIN (J = 3/2)

Ω_{ccc}^{++}

THREE CHARM QUARKS

SELEX candidate

not yet observed → Ξ_{cc}^+ dcc   ucc Ξ_{cc}^{++}

scc

TWO CHARM QUARKS

Ω_{cc}^+

Σ_c^+

Σ_c^0 ddc   udc   uuc Σ_c^{++}

dsc   usc

Ξ_c^0 ssc Ξ_c^+

ONE CHARM QUARK

Ω_c^0

Δ^- Δ^0 Δ^+ Δ^{++}

ddd   udd   uud   uuu

Σ^- dds   uds   uus Σ^+

Σ^0

Ξ^- dss   uss Ξ^0

NO CHARM QUARK

sss

Ω^-

$\Xi_{cc}^{++}(J=1/2) = ccu++$

$ccu++ \rightarrow L_t^+ K^- p^+ p^+$

$\Xi_{cc}^+(J=1/2) = ccu+$

$ccd+ \rightarrow L_t^+ K^- p^+$

$\Xi_{cc}^{++}(J=3/2) = ccu*++$

$ccu*++ \rightarrow L_t^+ K^- p^+ p^+$

Many Doubly Charmed Baryon Models

Author	Year	Model	$\Xi cc(J=3/2)$	$\Xi cc(J=1/2)$
Bjorken	1986	Phenom	3.70 GeV	3.64 GeV
Fleck & Richard	1989	Bag	3.636	3.516
Fleck & Richard	1989	Quarkonium	3.741	3.613
Roncaglia	1995	Feynman/Hellamn	3.81	3.66
Ellis	2002	Phenom	3.711	3.651

Sampling of Models
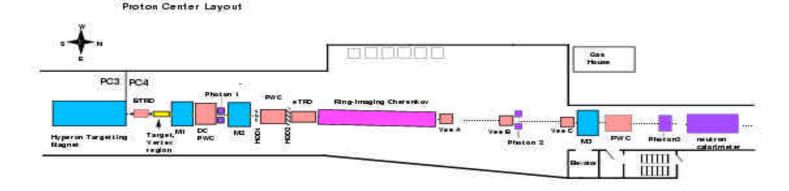
Overall Features
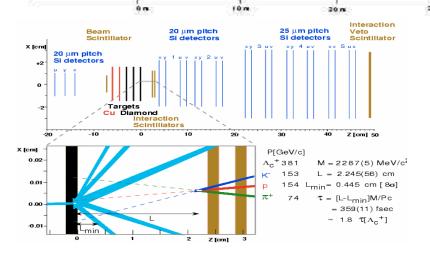
- ground states near 3.6 GeV
- ground states I=1/2 multiplets degenerate
- Hyperfine splitting around 60-120 MeV
- Most models predict on electromagnetic hyperfine transitions
- Some models predict pionic transitions for J=3/2 - J=1/2
- Model dependent predictions for orbital and radial excitations

SELEX Experiment at Fermilab

Data taken 1996-7 in P-Center @ FNAL

SELEX Experiment
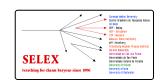
- Forward charm production $x_F > 0.1$
- π^- p and Σ^- beams @ 600 GeV
- Typical boost ~100
- RICH PID above 22 GeV
- 20 plane - 4 view svx - $\sigma > 4\ \mu m$
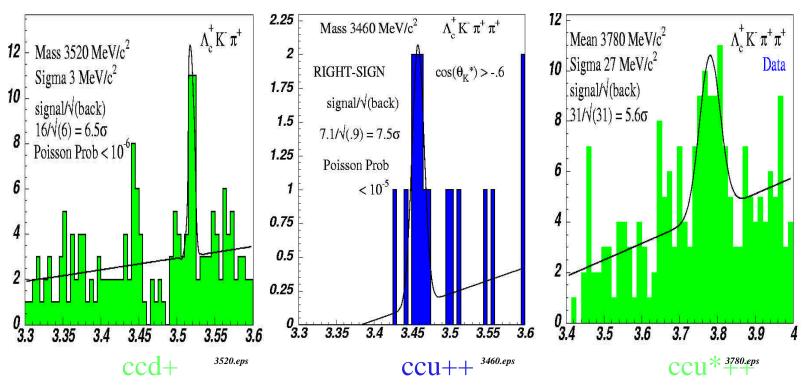
Experimental Evidence from 2002
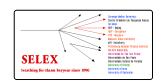
SELEX reported 3 significant high mass peaks

$\Lambda_c^+ K^- \pi^+$

Mass 3520 MeV/c^2
Sigma 3 MeV/c^2
signal/$\sqrt{}$(back)
$16/\sqrt{}(6) = 6.5\sigma$
Poisson Prob < 10^{-6}

ccd+   3520.eps

$\Lambda_c^+ K^- \pi^+ \pi^+$

Mass 3460 MeV/c^2
RIGHT-SIGN
$\cos(\theta_K^*) > -.6$
signal/$\sqrt{}$(back)
$7.1/\sqrt{}(.9) = 7.5\sigma$
Poisson Prob
< 10^{-5}

ccu++   3460.eps

$\Lambda_c^+ K^- \pi^+ \pi^+$

Mean 3780 MeV/c^2
Sigma 27 MeV/c^2
signal/$\sqrt{}$(back)
$31/\sqrt{}(31) = 5.6\sigma$
Data

ccu*++   3780.eps

We argued that these states are doubly-charmed baryons
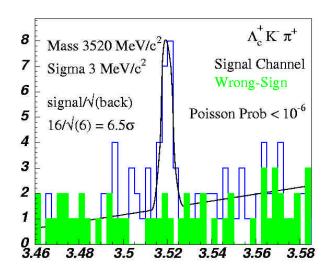
Search strategy and results

> **ccq** weak decays into **csq**. Look for charm, strange and baryon in the final state, starting with Selex's L_t^+ sample: $L_t^+ K^- p^+$, $L_t^+ K^- p^- p^+$

> Look for new secondary vertex between primary and L_t^+

> No RICH PID on new $K^- p^+$ tracks (5-20 GeV/c - too soft)

> All cuts set (and fixed!) from previous searches (e.g. $L/\sigma > 1$)

ccd$^+$(3520) results

> Fix L_t^+ mass to 2284.9 MeV/c^2 (PDG)

> Right sign has a mass peak at 3520 consistent with resolution. Wrong sign ($L_t^+ K^+ p^-$) has no structure.

> 15.8 signal, 6.2 background, $15.8/\sqrt{6.2} = 6.3s$

> Possion Prob=1x10^{-6} ; anywhere, 1.1x10^{-4}

ccd$^+$(3520) Iso-partner?
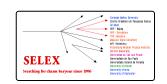
➤ Same cuts as ccd$^+$ ~3.5σ hint in **L$_t^+$K$^-$ p$^+$ p$^+$**

➤ Nothing in wrong sign: **L$_t^+$K$^+$ p$^-$ p$^+$**

➤ cos θ^*_K for mass sidebands (soft vtx tracks).
Set cut with S$_{MC}$/sqrt(B$_{tot}$), (cos θ^*_K >-0.6)

➤MC signal is flat, expect: s → 0.8s, b → b/3
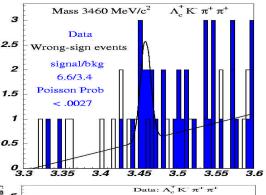
ccu^{++} results
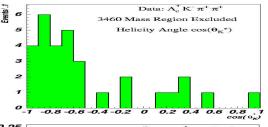
➤ Right sign has a mass peak at 3460 consistent with
resolution,**L=0**. Wrong sign (**L$_t^+$K$^+$ p p**) - no structure.

➤ 7.1 signal, 0.9 background, 7.5σ, Possion Prob <10^{-5}

➤ 60 MeV is **too big** for an isospin splitting.
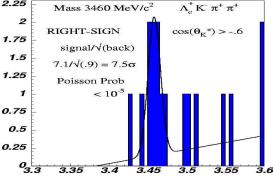
Doubly charmed baryons: Ξ_{cc}^{++}(3460), Ξ_{cc}^+(3520)
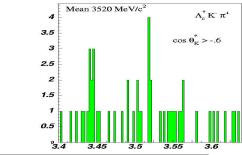**Hard to understand these as an Isodoublet**
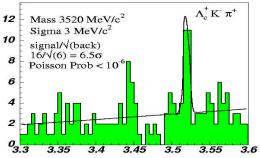
Where are the Iso-partners?

➢ MC signal for phase space **ccd⁺(3520)** decay is flat

➢ What happens if we apply cos θ^*_K >-0.6 cut here?

➢ **ccd⁺(3520)** strongly attenuated: **16 / 6 ® 5 / 1**

➢ **ccd⁺(3520)** clearly not like phase space ® **L>0**
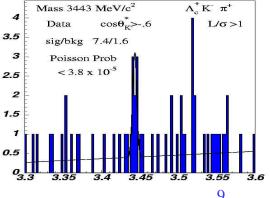
➢ Not Isodoublet with 3460 – different angular dist

New ccd⁺(3443) candidate now very significant

➢ Before cut we ignored bump at 3443 – only 4σ

➢ Background departs - bump at 3443 remains

➢ 7.4 signal, 1.6 background, 5.8σ, Prob<3.8x10⁻⁵

➢ Consistent with **L = 0 : 11 / 7 ® 7.4 / 1.6**

➢ A partner for the **ccu⁺⁺(3460)** ΔM=17 MeV
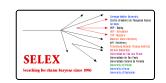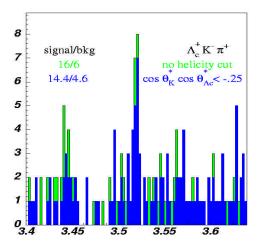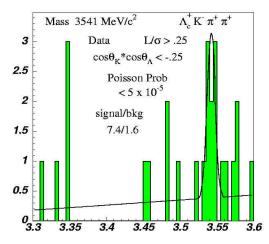
ccd⁺(3520) Iso-partner?

> **ccd⁺(3520)** mostly has $\cos \theta^*_K < -0.6$

> **L$_t$⁺** and **K⁻** back-to-back: $\cos \theta^*_K \cos \theta^*_{\Lambda c} < -0.25$ keeps 90% of the **ccd⁺(3520)** signal

> Apply to the ccu⁺⁺ sample to search for an Iso-partner for the **ccd⁺(3520)**

> No signal / little background with $L/\sigma > 1$.
> Try reducing cut to $L/\sigma > 0.25$
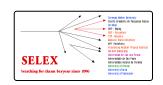
New ccu⁺⁺(3443) candidate now very significant

> Bump at 3443 remains – background departs

> 7.4 signal, 1.6 background, 5.8σ, Prob<3.8×10^{-5}

> Consistent with **L > 0**

> A partner for the **ccd⁺(3520)** $\Delta M = 21$ MeV

Figure (upper): signal/bkg 16/6, 14.4/4.6; $\Lambda_c^+ K^- \pi^+$; no helicity cut; $\cos \theta^*_K \cos \theta^*_{\Lambda c} < -.25$

Figure (lower): Mass 3541 MeV/c²; $\Lambda_c^+ K^- \pi^+ \pi^+$; Data; $L/\sigma > .25$; $\cos\theta_K^* \cos\theta_\Lambda < -.25$; Poisson Prob $< 5 \times 10^{-5}$; signal/bkg 7.4/1.6
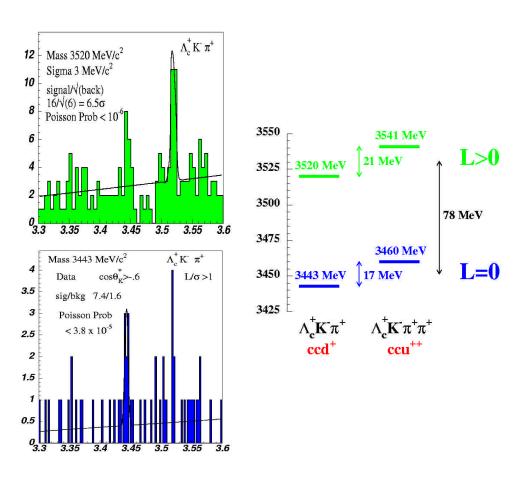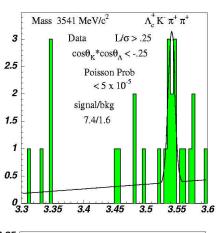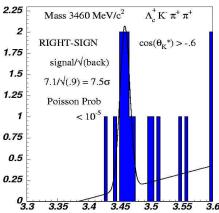
Recap - A Pair of Isodoublets?
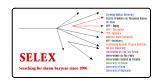
Lifetimes

- ➢ Selex uses reduced proper lifetime technique

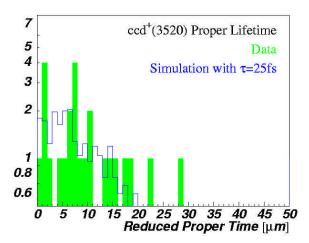$$c\boldsymbol{t} = m/p_z\,[L - L_{\min}]; L_{\min} = \boldsymbol{s}$$

- ➢ Make simulation templates for different lifetimes

- ➢ Lifetimes of all states near our resolution limits

  <30 fsec ; 0 not ruled out

Model Predictions

- ➢ Guberina, et.al. HQET + 1/M_Q

  - ▪ $\tau[\Xi_{cc}^{+}]$ ~ 200 fsec

  - ▪ $\tau[\Xi_{cc}^{++}]$ ~ 1000 fsec

- ➢ Observed states don't seem to follow predictions

- ➢How can the decay rate for ccq states be so large?

ccd^{+}(3520) Proper Lifetime
Data
Simulation with τ=25fs
Reduced Proper Time [μm]

Production

Beam Hadrons

	$\mathbf{\Sigma^-}$	proton	$\mathbf{p^-}$
Luminosity fraction	0.77	0.13	0.10
ccu^{++}(3443) signal/ sidebands	6 /10	2 / 2	0 / 1
ccu^{++}(3460) signal/ sidebands	8 / 9	3 / 0	0 / 0
ccd$^+$ (3520) signal /sidebands	18/18	4 / 1	0 / 1
ccd$^+$ (3541) signal /sidebands	7/10	4 / 1	0 / 1
	86	**17**	**3** (**11?**)

Dominantly produced by baryon beams

for ccd+ $\langle x_F \rangle$ ~0.35 (200GeV), $\langle p_t \rangle$ ~1 GeV/c - like single charm SELEX

➢ **Focus (E831) has looked in 250 GeV/c photo-production**

NO signals with 20K $\mathbf{\Lambda_t^+}$, many other modes searched **-** no signals anywhere

➢ **E791 has looked in 250 GeV/c $\mathbf{p^-}$ production -** no signals

Conclusions

SELEX
Searching for charm baryons since 1996

➢ Selex reports 4 high mass baryon states in an apparent pair of Isodoublets.

- Lower mass doublet is consisent with **L = 0** decay

- Upper mass doublet is inconsisent with **L = 0** decay

➢ All 4 states decay like doubly charmed baryons with very short lifetimes (<30fs)

➢ The splitting (~19 MeV) is large for an isodoublet.

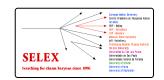➢ Radiative decays (e.g. 3520 ® 3443 γ) suppressed below weak decay rate?

Where do these states fit into our theoretical framework?

➢ Bardeen, Eichten and Hill and suggest these might be the spectroscopy of the **cc** "nucleus" of a **ccq** baryon:

$$J^P = 1/2^+ \left[c \uparrow c \uparrow L = 0, J^P = 1^+ \right] q \downarrow \qquad J^P = 1/2^- \left[c \uparrow c \downarrow L = 1, J^P = 1^- \right] q \downarrow$$

➢Predicted splitting consistent with observed 78 MeV

➢First EM transition is **M2**. Decay rate ~ 1/1.5 [fsec]
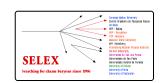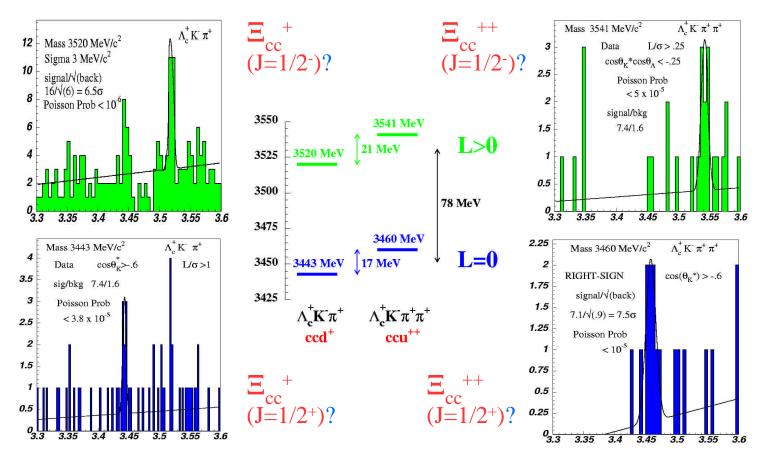
Conclusions (2)

Other Interpretations

➢ Narrow very high mass singly charmed baryon states?

- Like Babar's $D_S^*(2317)$ and Cleo's $D_S^*(2460)$?

- Quark content of $\mathbf{L_t^+ K^- p^+ p^+}$ is a pentaquark $[csu\bar{d}u]$ not a baryon

- Why should there be ultra narrow baryon states with Q~500 MeV?

Open questions

➢Production

- 1/2 of Selex's $\mathbf{L_t^+}$ of come though these states

- Only seen in forward production by baryons , no π or γ production

➢ Radiative decay rate – can EM really be slower than weak?

➢ Who else could confirm? CDF / D0 , Belle/Babar, BTeV /LHCb, Compass
Selex ($\mathbf{pD^+K^-}$)

Selex observes two Pair of Doubly Charmed Baryons: Two Isodoublets?

Ξ_{cc}^+
$(J=1/2^-)$?

Ξ_{cc}^{++}
$(J=1/2^-)$?

L>0

78 MeV

L=0

3550
3541 MeV
3525 — 3520 MeV   21 MeV
3500
3475
3460 MeV
3450 — 3443 MeV   17 MeV
3425

$\Lambda_c^+ K^- \pi^+$ $\Lambda_c^+ K^- \pi^+ \pi^+$
ccd$^+$ ccu^{++}

Ξ_{cc}^+
$(J=1/2^+)$?

Ξ_{cc}^{++}
$(J=1/2^+)$?